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THE SODIUM LAMP

FROM LABORATORY EXPERIMENT TO STREET LIGHTING

by E. G. DORGELO and P. J. BOUMA.

Summary. A short survey is given of the technical problems encountered in the development of discharge lamps using sodium vapour. The development led a) to a low tension arc for direct current and b) to a positive column lamp for alternating current. The latter has meanwhile almost entirely superseded the direct current lamp. Following a technical description of the lamps, the properties of their light are discussed as well as the possibilities of application which follow from these properties.

Since street lighting is the most important application, the circuits and installation of sodium lamps for street lighting are gone into in some detail, while finally some results are given of investigations on the visibility on roads lighted with sodium light.

Introduction

When one considers the fact that the light from a discharge in sodium vapour consists chiefly of radiations of a single wave length (5890/5896 Å), and moreover that the sensitivity of the eye for this wavelength, is very great being 76.5 per cent of the maximum value [1]), it is understandable that attempts have been made for some time to apply such a discharge in the construction of a practical high efficiency source of light.

Innumerable difficulties and problems had to be solved before sodium lamps were developed to such a point that they could be installed in large numbers for street lighting; only when this stage had been reached was it possible to form a satisfactory opinion about the utility of sodium light, and the influence of its unusual composition on visual acuity.

Development of the lamp

Since the vapour pressure of sodium at room temperature is so low that no discharge can occur, the lamp is provided not only with sodium but also with a rare gas filling. This latter gas makes ignition possible, while in addition the rare gas discharge heats the glass wall, so that after some time the pressure of the sodium vapour becomes sufficiently high to cause the sodium light radiation to predominate. Two problems immediately arose, namely that of the heat insulation, which is necessary in order to raise the lamp to the correct temperature with the least possible energy, and which must ensue that this temperature is not too greatly affected by the temperature of the surroundings, and that of the kind of glass: the "ordinary" kinds of glass are strongly attacked by sodium vapour at these temperatures (250 - 280° C). They become brown or black in a short time and then absorb very much light.

The first problem was solved in this laboratory by surrounding the lamp with a removable double-walled evacuated glass container. The contents of such a container can easily be brought to a given temperature and kept at that temperature, since, of the three forms of dissipation of heat, radiation, conduction and convection, the last two are practically ineffective here. Another system which is also used, that of mounting the lamp permanently in an evacuated outer bulb, makes a somewhat simpler construction. A disadvantage of latter system is the fact that the lamp must always be replaced as a whole, while the removable vacuum glass can always be used again. Moreover, the circulation of air between the vacuum glass and the lamp promotes uniformity in the temperature distribution.

[1]) Characteristics of the eye with special reference to road lighting, Philips techn. Rev. **1**, 102, 1936.
The representation of colour sensations in a colour space-diagram or colour triangle, Philips techn. Rev. **2**, 39, 1937.

Since the reaction with the glass appeared to consist in the reduction of the silicates present in it, silicon-free glass or glass poor in silicon, borate glass among others, was used at first. Since, however, this glass is very difficult to work with, due to the short transition interval in softening, we changed over to an ordinary glass which was protected from attack by a thin layer of borate glass. This glass was easily workable and almost entirely unattacked.

The solution of these two main difficulties made possible the construction of an efficient sodium lamp.

Further development was carried out in two different directions: that of the low tension arc, where the distance between the electrodes is small and the working voltage low (10 - 30 volts), the lamp being usually bulb-shaped, and that of the positive column discharge with a greater distance between the electrodes, a higher voltage (100 volts or more) and straight or bent tube-shaped lamps. We shall not go into the fundamental differences between the two forms of discharge. The low tension arc is in many respects comparable with the discharge in a rectifying valve [2]); the positive column discharge with the discharge in neon advertising signs. The low tension sodium arc here described (*fig. 1*) has been able to hold its own only in the case of direct current installations mainly because its length of life with alternating current was not sufficiently long.

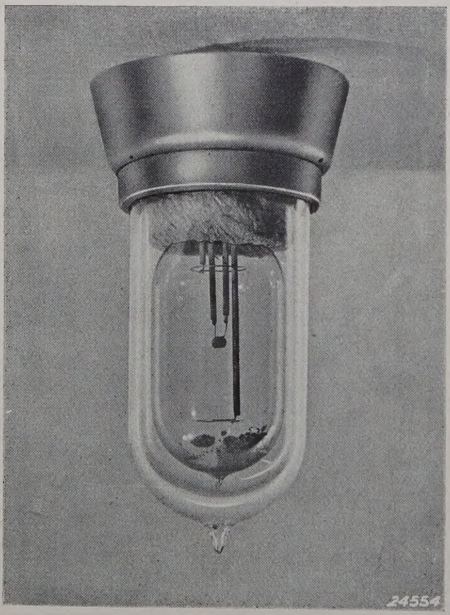

Fig. 1. Latest model of the low tension arc for direct current. Heat insulation by means of a removable vacuum glass.

In order to make use of direct current mains of the order of 220 volts a number of lamps were connected in series with a common series resistance.

The positive column lamp is now generally used with alternating current. In order to be able to include the connections for both electrodes in one cap the tube is bent in the form of a single or a double U (*fig. 2*). One of the problems encountered in the development of both types of lamps is that of the distribution of temperatures. In order to obtain a sufficiently high vapour pressure (about 10^{-5} atm) the temperature of the coldest part of the lamp must be about 250 - 280° C, while the rest of the walls of the tube may not be much hotter because of possible attack on the glass. A fairly uniform temperature of the walls is thus required. The method of sealing in, usual in the manufacture of electric light bulbs (see *fig. 3a*), (in which the lead-in wires are previously fastened into a glass foot which is fused into the bulb), is less suitable for sodium lamps since it is difficult to keep the place where the foot is fused into the neck of the bulb at the right temperature, while in addition the place where the connection wires are sealed in (the "pinch") becomes very hot, so that there is the danger that the glass along the wires will crack. Therefore, a special method of construction has been developed for sodium lamps (fig. 3*b*), in which the sealing-in wires are sealed in directly in the neck of the bulb (so-called reversed pinch). Especially in the case of the U-shaped positive column lamps has this method of sealing in proved effective. Both pinches are formed at

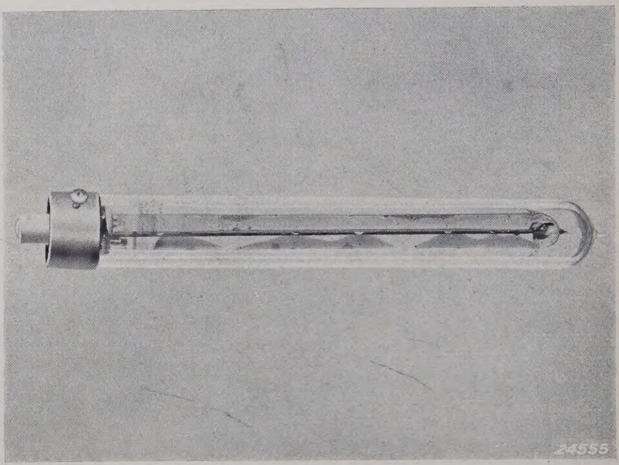

Fig. 2. Latest model of a positive column lamp for alternating current with vacuum glass. Tube bent in U shape. Running voltage 170 volts; current 0.6 A. Hot cathodes heated by the discharge.

[2]) Physical principles of gasfilled hot-cathode rectifiers, Philips techn. Rev. 2, 122, 1937.

the same time mechanically. For low tension arc lamps the construction shown in fig. 3c is also used, in which the space around the foot is isolated from the discharge by means of a chrome iron plate.

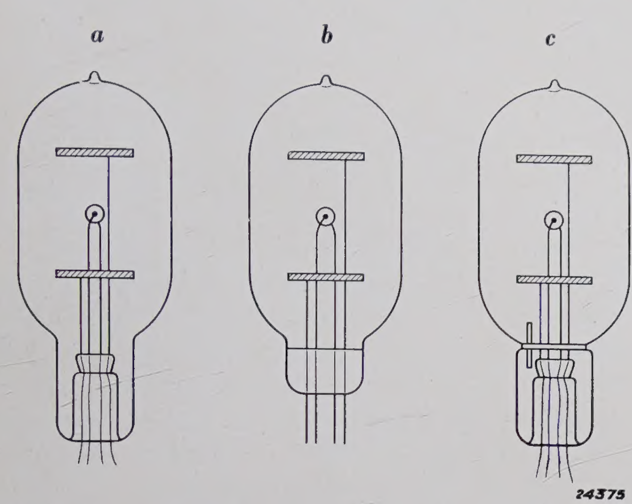

Fig. 3. a) Normal sealing in. The space around the foot is at too low a temperature so that when used as a sodium lamp the sodium condenses at this spot.
b) Leading-in wires attached directly to the neck of the bulb. The harmful cold space is here avoided.
c) Like a) but with a partition between the discharge space and the space around the foot. The condensation of Na vapour around the foot can also be avoided in this way.

In the low tension arc lamp the electrode system consists of a cathode in the centre of the discharge space, and two ring-shaped anodes situated about 2 cm above and below the cathode.

The cathode, which is wound in a spiral, is heated by current from a separate transformer. Its electron emission is large due to a film of alkaline earth oxides deposited upon it.

The positive column lamp, which is fed with alternating current, as already mentioned, has at each end of the tube one electrode which is wound in a spiral like the cathode of the low tension arc lamp. The function of this electrode is more complicated, however, since it must serve not only as cathode (in the negative phase) but also as anode (in the positive phase). Especially under the latter circumstance the heat to which the electrode is subjected due to the discharge is so great that a special heating current transformer is unnecessary.

A problem which must receive particular attention in the case of the positive column discharge is that of the distribution of the sodium. In order to obtain a uniform light from all parts of the lamp, it is necessary that the same concentration of sodium vapour be present in all parts of the bulb (or tube). The uniformity of distribution is threatened by different effects, such as one-directional movement of the ions due to a direct current component and differences in temperature. The influence of such effects is particularly great since the diffusion which seeks to promote uniformity is very weak in the case of sodium vapour in a gaseous atmosphere. With low tension arcs this fault is less serious due to the symmetrical construction of the lamp with the discharge in the centre. With positive column lamps the non-uniformity of the distribution of the sodium may cause some parts of the lamp to give less light than others; in extreme cases only the radiation of the rare gas remains in these parts. Little by little the causes of the non-uniformity have been successfully overcome, in the first place by providing for an even temperature distribution, and in the second place by keeping the transport of ions within definite limits (both the electrodes of the alternating current tube should be prepared in exactly the same way; since the conductivity is then the same in both directions, practically no direct current component occurs).

The problem of the dependence on temperature was found to be especially important in connection with the practical application. We have already seen that the temperature must be about 250 - 280° C. At a higher temperature and pressure the intensity of the light is found to increase only very slightly, and then to decrease again. Since more energy must be supplied for the higher temperature, the efficiency (lumen per watt) thus decreases. *Fig. 4* gives the light intensity as a

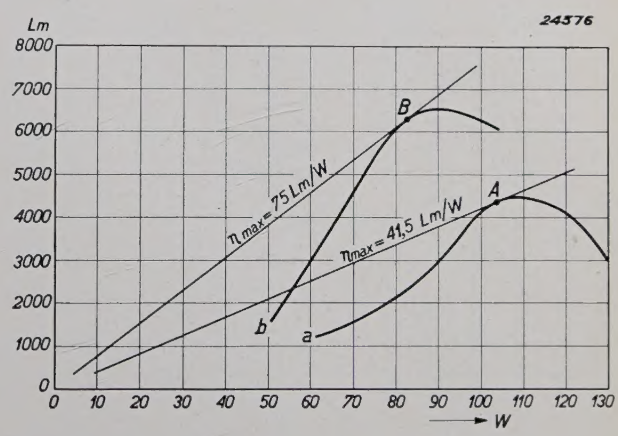

Fig. 4. Intensity of light (lumens) as a function of the power. a) Low tension arc on direct current. b) positive column lamp on alternating current. The curves do not represent average values but were measured on two individual lamps.

function of the energy input for two given lamps:

a) for a low tension arc lamp on direct current,
b) for a positive column lamp on alternating current.

The tangents to the curves from 0 give the points *A* and *B* where the lamps have their maximum

efficiency. In practice it was found advantageous to let the lamps work in the horizontal portion of the characteristic: the variations in the energy supplied (mains voltage variations!) as well as variations in the external temperature then have only little influence on the intensity of the light.

The properties of sodium light

As the above-mentioned problems and difficulties were more and more already overcome, and the lamps reached the stage of practical application, the study of the properties of this new kind of light was also begun. Considering that results of several of these studies have already been described in this periodical, a brief outline will be sufficient here.

The monochromatic character and the favourable spectral position of the sodium lines in relation to the curve for the sensitivity of the eye have been pointed out in the introduction.

With the first experimental installations it was remarkable how sharply small objects could be seen by sodium light. It is therefore understandable that the first physiological-optical investigations were concerned with the acuity of vision [4]). In connection with the monochromatic nature of the light and the consequent lack of chromatic aberration, and also from earlier experiments by Ives an important difference from ordinary electric light was to be expected. The acuity of vision with sodium light was actually found to be considerably greater. It is remarkable that the magnitude of this difference was found to depend upon the nature of the test objects used.

In the case of speed of perception [3]) also, which is closely related to acuity of vision, important differences between sodium light and ordinary electric light were found.

Upon continuation of this study it became clearer and clearer that the improved acuity of vision, although one of the most striking phenomena, is certainly not the only factor which determines vision with different coloured light, and that especial attention must be devoted to still another side of the problem, namely that of contrasts [4]). In the beginning it proved very difficult to confirm by means of laboratory experiments the general impression of the better contrasts on a road lighted by sodium light. The differences in sensitivity to contrast were too slight to explain the striking phenomena; nor did the measurement of coefficients of reflection for the various kinds of light show any important differences. A critical study of the concept of brightness and the Purkinje effect led us by way of the concept of subjective brightness [5]) to that of richness in contrast [4]). Along these lines it could be shown how the greater contrasts with sodium light are to a large degree related to a shifting of the curve for the sensitivity of the eye which is strongest at just the brightness occurring on a well-lighted road.

Since all these characteristics of the eye can be influenced very strongly by glare [6]), it was interesting to make comparisons between the different kinds of light in this respect also. The result was that for simultaneous glare no important differences could be shown, but that sodium light presents appreciable advantages with respect to successive glare as well as with respect to disturbing effects. The low brightness of the sodium lamp (compared with that of the mercury lamp for instance) was found to be important in this connection.

Little is yet known about the psychological effects of this new kind of light; in general it may be said that on country roads the yellow colour makes a restful impression on the great majority of road users. Experiments carried out in workshops and offices showed that the fatigue phenomena were equally great for white light and sodium light.

The range of application

Simultaneously with the physiological-optical study the investigation of the possibility of application was carried out. Although this problem was often attacked by intuition and by the method of trial and error, we may now conclude directly from the results mentioned in the previous section as to the conditions under which sodium light may be used to advantage.

Because of its monochromatic character we can employ sodium light only where the reproduction of colour is of no importance [7]). Its use in living rooms, shops, streets in the centre of cities, etc. is therefore immediately eliminated.

Moreover, in cases where very low intensities are

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[3]) Visual acuity and speed of vision in road lighting, Philips techn. Rev. 1, 215, 1936, other literature is cited in this article.

[4]) The perception of brightness contrasts in road lighting, Philips techn. Rev. 1, 166, 1936.

[5]) The definitions of brightness and apparent brightness and their importance in road lighting and photometry, Philips techn. Rev. 1, 142, 1936.

[6]) The problem of glare in highway lighting, Philips techn. Rev., 1 225, 1936.

[7]) The perception of colour, Philips techn. Rev. 1, 283, 1936. Colour reproduction in the use of different sources of "white" light, Philips techn. Rev. 2, 1, 1937.

usual, as for example in mines, sodium light cannot be used, since in these cases the Purkinje effect has an unfavourable influence on vision.

The use of sodium light will offer particular advantage in those cases in which acuity of vision is very important, such as the inspection of articles for fine cracks, or when quickness of perception plays a part (on tennis courts for example) [8]). When, as in the case of the lighting of country roads, the levels of brightness are of such a nature that in addition to these advantages that of the great richness in contrast becomes important, the sodium lamp will often be the most suitable source of illumination. Wherever glare must be avoided or kept at a minimum, the sodium lamp with its low brightness, its slight successive glare and its relatively pleasant colour offers great advantages.

Further there is a long series of applications in which special use is made of the pronounced yellow colour of the light. The advantages of this colour may be manifested in very different ways:

1. Aesthetic effects may be obtained when the light is used as flood lighting for buildings, as part of festival illuminations, illumination of groups of trees, etc.
2. Certain objects such as advertising signs, signals, etc., can be given a very striking appearence by means of sodium light; its use for boundary lights of aerodromes belongs to this category.
3. In various special cases small contrasts become much clearer in sodium light, because the differences in coefficient of reflection may be greater than with illumination by white light. This applies particularly to various cases of the testing of materials.

Sodium light is already being used in the photographic studio [9]).

Finally sodium light will often be used for purely economic reasons in cases where large areas must be lighted (shunting yards) or where for special reasons road lighting of a very high intensity must be used (traffic tunnels in the daytime). Sodium light in such cases presents entirely new possibilities, since illumination with ordinary electric lamps is often extremely expensive.

Circuit and electrical characteristics of sodium lamps [10])

In the low tension arc lamps used with direct current the two anodes are connected to each other so that the lamp has three connections: one positive terminal and the two ends of the heated cathode as negative terminals. *Fig. 5* gives a complete diagram of a number of lamps connected in series. For heating the cathode each lamp has a separate heating current transformer T which is fed with alternating current. In addition there is a cut-out cartridge S in parallel with each lamp, which breaks down when the lamp does not work, and thus keeps the circuit closed. Since in such a circuit the direct voltage applied is at first distributed unevenly over the various lamps so that the lamps may light one after another, the ignition voltage required per lamp may be considerably lower than that for one single lamp (this is about 30 volts). Consequently only about 10 per cent of the total voltage need be lost in a series resistance, which often takes the form of an iron wire in an atmosphere of hydrogen. This series resistance keeps the current constant in spite of variations in the mains voltage or changes in the

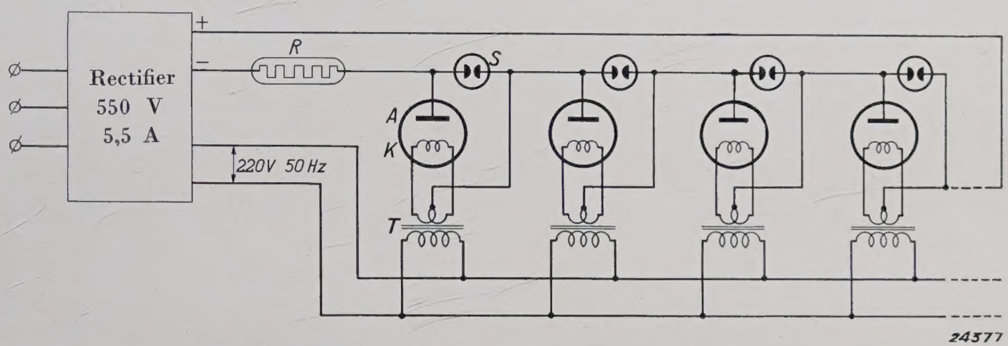


Fig. 5. Diagram of a series installation with low tension arc lamps. A anodes, K cathodes, T heating current transformers, R iron wire resistance, S short-circuiting cartridge.

8) Sodium lighting of tennis courts, Philips techn. Rev. **1**, 252, 1936.

9) The "Philora" sodium lamp and its importance to photography, Philips techn. Rev. **2**, 24, 1937.

10) Alternating-current circuits for discharge lamps, Philips techn. Rev. **2**, 103, 1937.

load resulting from the falling out of lamps. Some of the objections connected with supply by direct current are the necessity of installing whole groups at the same time, the four-conductor system (see fig. 5), the relatively high sensitivity to variations in temperature and the occurrence of radio interferences which may, however, be suppressed by installing filters [11]).

We are giving herewith some data of a direct current installation (first street lighting with sodium lamps, June 1931, Beek - Geleen, Holland).

Total direct voltage: 500 volts.
Voltage across the series resistance (average): 50 volts.
Sum of the voltages of the individual lamps: 450 volts.
Number of lamps: 30
Current 5.5 A.
Consumption of lamp including heating current transformer: 102 W
Total consumption: 3.1 kW.
Luminous flux per lamp: 4000 lumens
Efficiency, gross: 38.5 lm/W.

The positive column lamp used with alternating current offered wider possibilities. In this lamp two hot cathodes are used for electrodes. These electrodes are raised and kept to the proper temperature by the discharge itself, and function as both cathode and anode alternately. A separate heating current transformer is therefore not provided. The current is limited by a transformer of special design. *Fig. 6* shows such a combination

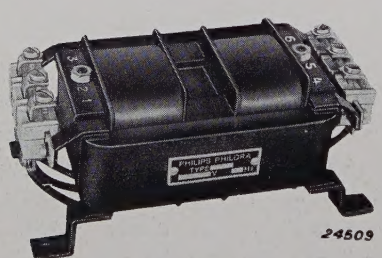


Fig. 6. Leakage flux transformer.

which is called a leakage flux transformer. The self-inductance of this transformer causes a phase shift between current and mains voltage which may be eliminated by the introduction of a correcting condenser across the mains terminals.

The A.C. lamps may be installed quite independently of each other. The following table (*table I*) gives some data of the lamps in use at the present time:

[11]) High-frequency oscillations in sodium lamps, Philips techn. Rev. **1**, 87, 1936.

Table I

Type	Power incl. losses in current limiting device	Current through lamp	Running voltage	Luminous flux	Efficiency
50 W	65 W	0.6 A	80 V	2 550 lm	39.3 lm/W
65 W	80 W	0.6 A	110 V	3 780 lm	47.3 lm/W
100 W	105 W	0.6 A	165 V	6 100 lm	58.1 lm/W
150 W	165 W	0.9 A	165 V	9 600 lm	58.2 lm/W

As may be seen the first three types take the same current. Because the current supplied by the leakage flux transformer due to its high impedance depends only slightly on the voltage of the lamp used, these types can be used with the same transformer.

Fig. 7 shows how the light flux increases as a function of the time elapsing after switching on.

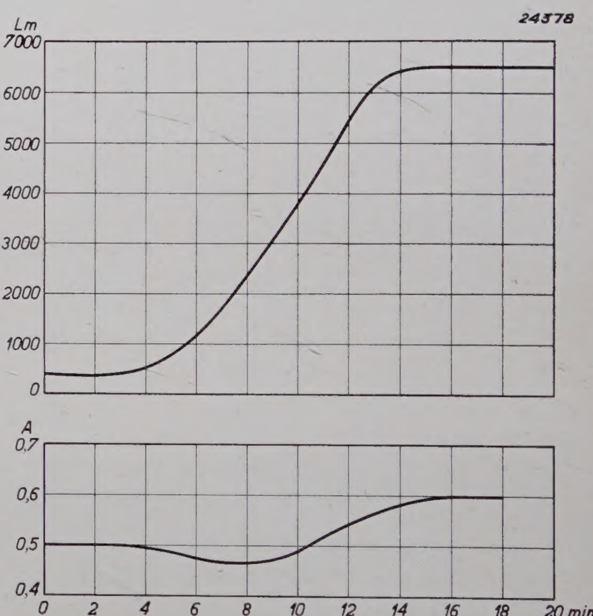


Fig. 7. Luminous flux (lumens) and lamp current (amperes) as a function of the time elapsed after switching on for a U-shaped lamp of 100 W on a transformer for 470 volts and 0.6 A.

The changes in light flux with variations in the mains voltage may be seen in *fig. 8*. For the sake of comparison the corresponding curve for an incandescent electric lamp is also shown.

We conclude this section with a few remarks about the life of sodium lamps, particularly of A.C. lamps.

While with ordinary electric lamps the length of life is chiefly determined by the rate at which the filament evaporates, and therefore has a value which may be foretold with fair accuracy, the length of life of sodium lamps depends upon a number of factors whose influence it is more difficult

to discover. Evaporation of the electrodes and the material deposited upon them occurs here also, but the available reserve is so great that the length of life of the lamp is not generally influenced by this factor. After several thousand

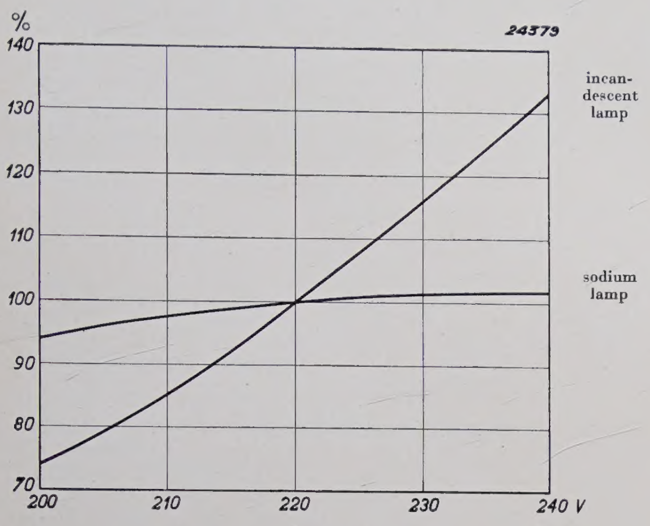


Fig. 8. Light flux of a sodium lamp and of an incandescent electric lamp for different mains voltages in per cent of the value reached at the nominal mains voltage of 220 volts. The sodium lamp is very insensitive to voltage variations.

hours, however, symptoms of age appear, which to a great extent may be ascribed to a less uniform distribution of the sodium. This may result in certain parts of the tube giving too little light. Local brown coloration of the glass may also result, while an abnormal accumulation of molten sodium in the neighbourhood of the electrodes may lead to cracking at the point of sealing in. On the average an A.C. sodium lamp lives 2 500 hours.

The installation of sodium lamps from the standpoint of lighting technology

We shall not go too deeply into this subject, and shall only discuss those points in which sodium illumination differs fundamentally from illumination by means of incandescent electric light.

These differences are due chiefly to the special form, dimensions and light distribution curve of the sodium lamp. Because of these differences special measures must often be taken in order to satisfy the general requirements of street lighting, such as the greatest possible uniformity, sufficiently high brightness of the road surface, little glare and good visibility.

If we consider the distribution of light from a sodium lamp (*fig. 9*), we see that the best position for the lamp is horizontal and perpendicular to the direction of the road. The greatest part of the light radiated downward then falls on the surface of the road and its immediate surroundings. In order to obtain illumination directly under the lamp the two arms of the U must lie in a horizontal plane.

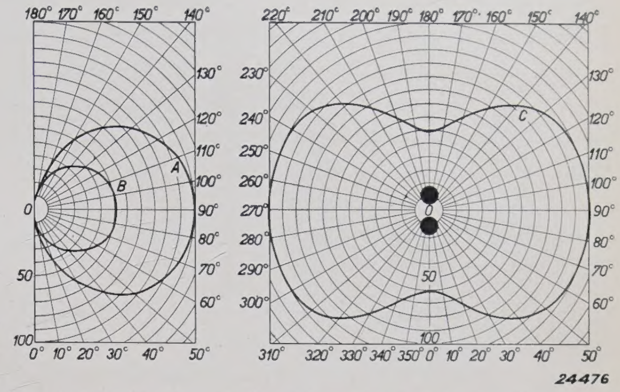


Fig. 9. Distribution of the light of a U-shaped sodium lamp in three different planes. *A*) plane through the axis of the lamp and perpendicular to that of the U-tube. *B*) plane through the axis of the lamp and coinciding with that of the U-tube. *C*) plane perpendicular to the axis of the lamp.

On the other hand for road lighting where it is desired to distribute the light more or less evenly over the whole surface of the road, it is better to place the two arms one above the other.

The part which serves chiefly to reflect the light radiated in an upward direction may be very simple in this case. In *fig. 10* may be seen a reflector, white-enamelled on the inner side and of such a shape that light rays which fall within an angle of 20° to the road surface are intercepted. Direct perception of the lamp at a greater distance

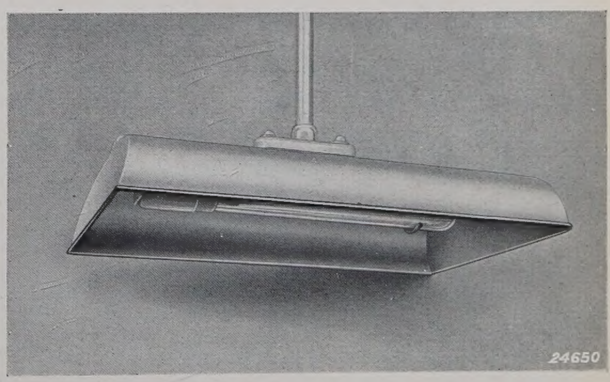


Fig. 10. Simple holder for sodium lamps.

is hereby impossible, so that glare is practically eliminated. Because of the fact that the vertical dimension of the light source is so small (about one inch) it is possible to cut it off sharply and yet retain a wide angle of radiation.

With existing installations the height of the light is usually 25 to 30 feet with a distance between

the standards of 100 to 120 feet. Using lamps of about 100 W a good illumination is obtained with this arrangement.

In certain cases (workshops where machines, cranes, etc. are used) the fact that the intensity of the light pulsates 100 times a second may cause stroboscopic effects. If this must be avoided two lamps may be placed in one holder, and their transformers may be so connected that the lamp currents are 90° out of phase with each other. The total light flux is then never zero, and the difficulty mentioned is thus avoided.

Appraisal of the result achieved

When sodium lamps have been employed in a lighting installation, especially for the lighting of a country road, after taking into due account practical experience as well as results arrived at through theoretical considerations it is interesting afterwards to find out to what degree the result achieved may be considered satisfactory. The appraisal of the result may be carried out in very different ways.

One method which may give very misleading results when injudiciously applicated, is to stand on the road and look. In general more attention is paid to the light sources than to the road, more to the total amount of light entering the field of vision than to the correct distribution of brightness, more to the impressiveness of the installation than to the visibility on the road. It is much better to drive along the road and to notice how the lighting influences the ease of driving and the feeling of security. The objection to this method is that it is difficult to express the result in figures. As has been explained in another place in this periodical [12]), this goal can be reached with the help of a **visibility meter**, an instrument by means of which the weakest contrast still observable on the lighted road can be established in a simple way: the weaker this contrast the more successful the lighting system.

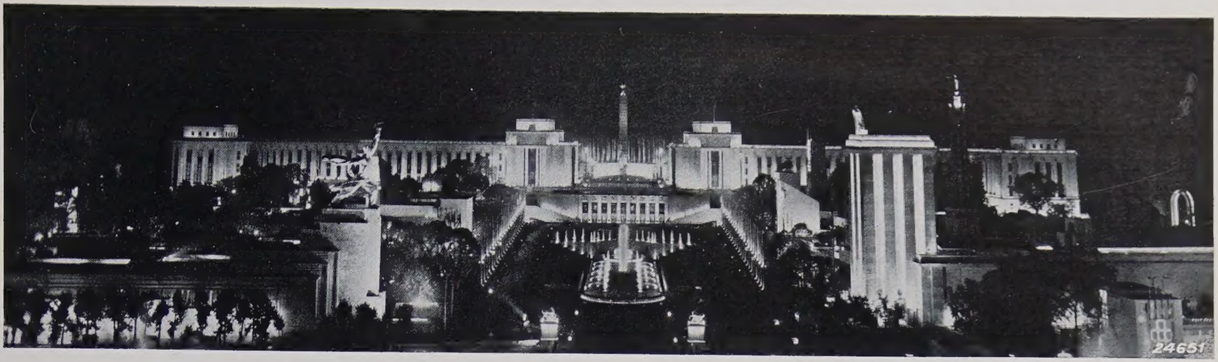
In *table II* are collected the average values of the weakest recognizable contrast for a number of different installations.

Table II.

No. of installations	Kind of light	Type	Power kW/mile	Weakest recognizable contrast (average)
14	Sodium	A	5.3	0.20
5	Mercury (and mixed light)	A	9.0	0.22
4	Mercury	V	15	0.395
5	Incandescent electric light	V	10	0.31

The letter *A* here indicates that a well-shielded light source was used, the letter *V*, that this was not the case. The great influence of glare due to insufficiently shielded sources of light may be seen: in spite of the high power installed the visibility is very low. With sodium lamp installations an excellent visibility is attained with a small power.

[12]) How can one judge the efficiency of road lighting?, Philips techn. Rev., 1, 349, 1936.



ILLUMINATION AT THE INTERNATIONAL EXHIBITION IN PARIS 1937.

by L. C. KALFF.

At every world exhibition the illumination forms an attraction which draws millions of visitors. Since the exhibitions at Barcelona and Seville (1929), it may even be said that the illumination has become one of the most important attractions. In the evening, after a day's work, when no particular desire is felt for studying the contents of the various pavilions, hundreds of thousands of visitors may still enjoy the outward aspect of the exhibition, and these visitors will judge the merits of the various countries and groups by the more or less successful illumination of their buildings.

In the series of exhibitions of the last 15 years there has been an interesting development in the technique of illumination.

After the example of Barcelona, which, under the gifted leadership of the engineer Carlos Buygas, and thanks to the unlimited financial support which he enjoyed, was an almost insurpassable technical and artistic success, an attempt has been made in succeeding exhibitions at Antwerp (1930), Vincennes (Exposition Coloniale 1931), Chicago (1933) and Brussels (1935) to continue the development of the new trend in illumination.

In Barcelona the illumination consisted mainly of floodlighting of the buildings combined with lighted columns of transparent glass along the avenues and gigantic illuminated fountains in changing colours. All these forms of illumination in all the possible colours were controlled from a small room in a tower. Buildings, columns and fountains could in this way be displayed in every colour combination from a central point.

Relatively few people in western Europe had the opportunity of admiring the illumination at Barcelona, so that for most of us the illumination at the exhibition in Antwerp was entirely new. The budget for this exhibition was much more modest, and the illumination was carried out on a much more modest scale, but if possible with even more effect.

In the first place the use of coloured light was given up, while as a new element of light decoration there was a large scale application of lighted columns of painted wood or plaster which give an indirect illumination. These columns were much cheaper than the glass ones of Barcelona, and had the additional advantage of making a pleasing effect by daylight, since they could be made of the same material as the surrounding buildings.

The chief impression which many will have carried away from Antwerp will be that of avenues flanked by rows of lighting elements, sometimes tall, in the form of stately columns, and sometimes very low, placed as lanterns along the narrower avenues among the shrubbery.

The colonial exhibition at Vincennes continued the development along the lines laid down at Antwerp. There, too, strongly illuminated surfaces were introduced as light carriers, often in fantastic forms such as palm leaves or roofs of pagodas to correspond with the different styles of architecture in the colonies. The architects Granet and Expert were chiefly responsible for presenting new attractions to the public in the shape of these lighting elements and particularly the magnificent fountains. The fountains, which were quite different from those at Barcelona with respect to form and illumination, enjoyed an enormous success. Illumination in colours was only rarely used in the exhibition. We recall particularly the splendid temple of Ankorvat which was metamorphosed by Jaccopozzi with golden yellow light into something from a fairy tale.

After Vincennes came the exhibition at Chicago, where from a technical point of view the illumination

did not offer much that was new, but where it could be seen that more colourful effects were being sought than had been achieved so far. Very simple means were used for this purpose in Chicago.

The floodlights for the lighting of different buildings were provided with colour screens, and the surfaces of the buildings which were to be illuminated were simply painted in primary colours corresponding with the colours of the screens of the floodlights. No change of colour was thus possible and in daylight the buildings were also very brightly coloured.

In 1935 came the exhibition in Brussels where all the above-mentioned methods of illumination were applied on a large scale. In addition extensive use was made of neon tubes, often in combination with floodlighting. A new departure at this exhibition was the extensive use of metallic vapour lamps for illuminating the exteriors of buildings. By this method variety in the colour of the buildings was obtained after dark in an economical and natural way. Next to the white light of ordinary electric lights the blue-green of mercury lamps and the golden yellow of sodium lamps could be seen. The liberal use of these lamps in the magnificent park, where the century-old beeches were lighted up in a startling way by this colourful light, was especially new and proved a great success.

It may readily be understood that the organizers of the 1937 Paris exhibition, after having seen the exhibition at Brussels, while admitting that it was very fine, wished to have everything as different and as new as possible in Paris in 1937. Everyone concerned, the committee of the exhibition as well as the architects and the manufacturers of the lamps and fittings, have done their very best to realize this ideal, and we shall attempt in the following description to examine the degree of success achieved.

Each of three architectural bureaux received a commission to design the illumination of a part of the exhibition, and to act as advisers in full authority for the illumination of the pavilions lying within their territory. These advisers were: for the part on the "rive gauche" of the Seine the architect Granet, for that on the "rive droite" the architect Expert, while architects Beaudouin and Lods, after a prize competition, were appointed designers of the light festivals on the Seine.

In designing the illumination the decision was made to avoid all light columns and other elements constructed solely for illumination throughout the whole exhibition. The buildings themselves together with the lighted fountains and trees would have to supply the light necessary for the circulation of the public in the evening. This principle was very consistently maintained. Almost nowhere throughout the exhibition grounds are there visible light elements such as columns and the like.

Several interesting conclusions may be drawn from the result of this method.

It goes without saying that the collection of pavilions which forms the exhibition is extremely heterogeneous. Each pavilion tries to be conspicuous among all the others by shape, decoration or dimensions. Because of this the illumination of each building formed a new problem demanding a solution. The unity which can be obtained by placing rows of light columns along a boulevard, even though it be bordered by very different buildings, is here sacrificed, but in its place there is a very interesting diversity of silhouettes and systems of illumination. Moreover, the various buildings may be viewed separately to better advantage than would be possible if light columns situated in front of them interfered with the view.

The systems of illumination used for lighting the different buildings are numerous, but the colour of the light is limited in the main to a few tints. Besides the white light of ordinary electric lamps may be seen the golden yellow of sodium lamps, the blue-green of mercury lamps and the light of several other gas discharge tubes in different colours. A greater variety is shown only by the light fountains, which work with colour screens in all colours, and the huge decorative dome of gas discharge tubes in many different colours under the first story of the Eiffel Tower, which was designed by architect Granet.

We shall give a survey of the most striking illuminations of the various buildings.

In the first place there is the new Trocadéro (*fig. 1*). The low middle sections, executed in light stone, glow in the strong white of ordinary electric light which is projected upon them by several batteries of floodlights, while the two curved wings are bathed in golden yellow light by a combination of sodium and ordinary electric lamps which give a fine warm colour to the limestone.

Above the cornice the building is terminated by an Attic story which is lighted by hundreds of electric lights with built-in silver mirrors.

This mighty building forms a beautiful background and termination for the international part of the exhibition. The pavilions of the various countries lie at the foot of this building rather close together and partially hidden by all the trees.

At either end of the Pont de Jena beside the

Fig. 1. This picture shows the entrance of the great underground banquet hall and part of the right wing of the Trocadéro. From the terrace above the hall one has a magnificent view of the fountains and the Eiffel Tower which lie along the main axis of the exhibition grounds (see the accompanying photographs).

Seine the buildings of Germany and Russia dominate by their size. Russia has brought out its grey stone façade and the two gigantic metal figures which crown its pavilion by means of an abundance of white light which gives the monument a bluish-white, almost immaterial aspect. Opposite to this stands the huge square tower of the pavilion of Germany, which is rendered almost transparent in the evening by the indirect illumination of long rows of lamps hidden behind the pilasters which divide up the surface of the tower. The lighted surfaces consist of partially gilded terra cotta which reflects the flood of light in a remarkably beautiful way.

Opposite these groups of buildings stands the Eiffel Tower, which continually changes its aspect. In the first place there is the dome of neon tubes already mentioned, but when these are not working the whole Eiffel Tower appears in all its delicate tracery lighted by 750 large projectors which are introduced into the iron work. The effect is startling and its colour is changed each week by changing the coloured filters in front of all the projectors. In addition, there are large search lights which send out blue-green beams straight upwards. These search lights are provided with Philips super high pressure mercury lamps with water cooling [1]), which form one of the novelties of the exhibition. Besides these search lights which are set up at the corners of the three storeys of the Eiffel Tower, there are eight more of them on the first storey (see the accompanying photographs). These eight beams of light may be moved from the vertical position until they form a fan of light which gives the impression of an immense peacock's tail unfolding. This gives an especially splendid effect on misty evenings.

Of the other buildings we must not fail to mention the new permanent museum of modern art (*fig. 2*), where the shape has not so much been adapted to the purpose of illumination, but where an interesting "claire obscure" has been obtained by an ingenious arrangement of the light sources in such a way that the reliefs and their reflection in the pool in front of the building give particularly fine effects.

The illumination of the Hungarian pavilion is

[1]) Philips techn. Rev. 2, 165, 1937.

Fig. 2. The new permanent museum which forms a part of the exhibition and which is also striking in the evening due to its fantastic illumination.

also very well carried out (*fig. 3*). The tower with its glass top, lighted by mercury light, comes out especially well among the green of the trees among which reflectors with mercury lamps are also placed.

Along the Seine the pavilion of the "Stations Thermales" (*fig. 4*) makes a very striking picture. Huge frescos in semicircular niches are lighted from the side by hidden sources. The whole building is one great light monument and deserves particular attention.

Then there is the attractive "centre régional", where buildings in the style of the different provinces of France are grouped about a square (*figs. 5* and *6*). In the evening the buildings give many pleasing glimpses of the characteristic architecture of the provinces by means of abundant and carefully arranged lighting.

Interesting adaptations of sodium and mercury lamps may be seen in the pavilion of Luxembourg and the tower of the "Pavilion du froid". The lower part of the façade of the Luxembourg pavilion exhibits a large relief representing the picturesquely situated city of Luxembourg. Hidden sodium lamps bring out the details of this relief in a golden light. The lighting of the upper band of the façade with ordinary electric light forms a contrast.

In the "Pavilion du froid" the applications of artificial cooling are exhibited. The tower is covered with a thin layer of snow which is brightly lighted with the blue-green light of mercury lamps (*fig. 8*).

When one enters the exhibition through the entrance between Grand Palais and Petit Palais, one first passes under the 300 feet high mast which, with its decoration of gaily waving signal flags, gives a foretaste of the festive spirit to be encountered farther on in the Parc des Attractions. To reach this Parc one passes over the Pont Alexandre, one of the monumental remainders of a previous exhibition, which, however, due to the twelve aluminium pavilions which comprise the exhibit of the Philips factories, is totally changed in appearance (see accompanying coloured photographs). It goes without saying that light is here the important element in bringing about the desired effect.

Above the stands which, bathed in a sea of light, exhibit the different Philips products in photograph and in actuality, the pylons glow in a blue-white light from ordinary electric lights and mercury tubes. These pylons are built up of aluminium organ pipes and appear as transparent as glass under the fantastic illumination. Seen especially from the Pont de la Concorde, where the 12 pylons are

reflected in the waters of the Seine, they form a magnificient termination to the exhibition grounds.

After this survey of the different notable buildings, we shall devote our attention to the illuminated fountains.

In the first place there are fountains in front of the Trocadéro (see enclosure). Between a double row of slender jets springs a mighty arc of water (*fig. 9*) which is lighted from below in different colours. The effect of this fountain is increased by the fact that a substance is dissolved in the water which fluoresces blue when irradiated with ultra violet light. On both sides of the fountain are long rows of Philips high pressure mercury lamps with bulbs of a glass which contains nickel oxide and which transmits only the ultra violet radiation. This invisible light causes the streams of water in the basin to shine with a blue glow. In addition the fountains are illuminated in other colours by light sources under the water, so that they are seen in a many coloured light. When the light from below is orange and it fades and changes slowly into blue, the effect is extraordinarily beautiful.

Fig. 3. Together with the trees surrounding it, the glass tower of the Hungarian pavilion glows in the blue-green light of mercury lamps.

Somewhat farther in the direction of the Place de la Concorde, the fontaines de Jeumont (*fig. 10*) may be found on the bank of the Seine, opposite the fashionable restaurant "Roi George". These fountains play in an almost endless series of variations. The form and colour is continually changing. 450 lamps of 1000 watts with different coloured screens here provide the illumination. An especially ingenious invention is an instrument which has the appearance of an organ and which contains a series of switches for making the changes in form and colour of this fountain. The "organ" stands in the restaurant "Roi George" on the other side of the river, and the guests of the restaurant may play upon it.

It will be obvious that we have been able to discuss only the largest and most striking installations, and that many have had to pass without mention.

When we ask ourselves finally what is our opinion of the result of the principle followed of having the illumination consist only of the light reflected from the buildings, we are compelled to mention several objections. The great wide boulevards especially in the evening give somewhat the impression of darkness. This of course brings out the buildings

Fig. 4. The immense frescos on the curved surfaces of the façade are irradiated from the side by hidden light sources.

all the better, but strolling about is decidedly pleasanter and more sociable when there is a bit more light on the public. The execution of the various pavilions has not always been sufficiently under control to provide enough unity and the use of adequate light.

We may conclude from this that a general illumination of the façades may be used with success, provided that architecture and illumination are more completely under one control. We are reminded in this connection of the splendid exhibition in Stockholm, designed by architect Asplund in 1930. To give a truly gay impression the surface of the thoroughfares must certainly be lighted to a certain extent in order to form a connection between the lighted buildings.

We arrive finally at the work of the architects Beaudouin and Lods, which, with respect to lighting, is surely the most remarkable and the most successful to be seen at this elaborate exhibition. At certain times, in the evenings, particularly at the "soirée de gala", tens of thousands collect on the Pont de Jena and along both banks of the Seine. A display then begins such as surely never before was seen. To the acompaniment of music specially written by well-known composers, the light fountains on both sides of the bridge and in the middle of the Seine begin to play. These fountains change continually in height and colour to the rhythm and in harmony with the mood of the music. Among the fountains gigantic clouds of steam are developed now and again, which are also lighted by coloured lamps. At the climax of the music, enormous bunches of rockets mount into the sky and conclude the different themes with peals of thunder. All kinds of clever inventions increase the effect, such, as for example, thousands of small balloons which are freed and then pursued by two huge beams from large naval search lights to dizzy heights where the balloons are visible in the bright light as clouds

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Eiffel Tower.

The iron construction of this tower is lighted by 750 large coloured beam lights. Further there are on the first storey eight searchlights with super high pressure mercury lamps. The beams of these searchlights can be moved from the vertical to a fan-shaped position.

The new Trocadero.

The low buildings in the middle are lighted by ordinary incandescent lamps of a powerfull white colour. The two curved wings radiate in a golden yellow blended light of sodium and incandescent lamps. The fountain before the Trocadero is lighted in several colours and moreover irradiated with ultraviolet light. A substance dissolved in the water fluoresces blue under the influence of these rays.

Pont Alexandre.

Twelf pavilions on this bridge, crowned with aluminium columns and lighted by means of incandescent lamps and mercury lamps, have been installed on the bridge by Philips.

Fig. 5. In the „Centre régional".

of fine confetti against the night sky. Floating lights in different colours drift with the water of the Seine, under the bridge, and Bengal lights behind the clouds of steam and water vapour add to the glow from the projectors installed under water. Sometimes fireworks burst from the Eiffel Tower at the same time, so that the spectator is surrounded on all sides by this feast of colour, shape and sound.

Fig. 6. Because of the carefully arranged lighting these buildings in the styles of the different French provinces offer many pleasing glimpses in the evening also.

The architects have achieved something quite unusual with this combination of music and light. It is obvious that the greatest ingenuity has been employed for this purpose. In the first place there was the problem of water-borne traffic. In the daytime this traffic could not be interfered with, so that all the fountains in the middle of the river had to disappear. Two means of doing this have been used. Part of the fountain is set up on floating buoys which are anchored on the river bottom. These buoys are connected to the bank by a cable so that the lamps can be lighted from the shore, while pumps working under water supply the water for the fountains. In the daytime the buoys are simply allowed to fill with water until they sink, while they can be brought to the surface again by being pumped full of air.

The larger fountains for water and steam are built on floating pontoons which can be towed away after the display.

The fireworks are also set up on floating pontoons and can be set off electrically, while the loud-speakers for the music are also floating and may be towed away.

Near the Belgian pavilion by the bank of the Seine lies a floating control station from which all these different instruments can be operated. An

extensive switchboard with dozens of knobs and a small studio for the playing of gramophone records are housed in this station.

A complete score has been written for every display, and fountains, lights and fireworks are indicated on the different "staves". In this way the operator in the control room knows what he has to do from moment to moment during the whole display.

Such a combination worked out to the tiniest detail is of course unique up to the present, and it is particularly these displays which have again put Paris at the head of all cities which have organized world exhibitions.

In order to illustrate the enormous developments in the adaptation of artificial light in exhibitions which has been made in the last decades, we may give the following figures of the total power installed at various exhibitions:

1925: Arts Décoratifs, Paris	9 000 kW
1929: World Exhibition, Barcelona	7 500 kW
1930: World Exhibition, Antwerp	4 000 kW

Fig. 7. Luxembourg's pavilion. The façade is lighted with different kinds of light. The huge relief of the city of Luxembourg is particularly striking in yellow sodium light.

Fig. 8. The snow-covered tower of this pavilion is lighted with blue-green mercury light.

1931: Colonial Exhibition, Vincennes near Paris	18 000 kW
1933: World Exhibition, Chicago	27 500 kW
1935: World Exhibition, Brussels	18 000 kW
1937: Exposition des Arts et Technique	62 500 kW

Apart from the range and extent of these different exhibitions, the increase by leaps and bounds in the power — the exhibition in Paris in 1931 showed double the power of that of 1925, and that of 1937 seven times that of 1931 — gives convincing proof that light plays a continually more important part in the organization of such exhibitions, but it also indicates how mankind is developing a need for more light. This need exerts great influence not only on social economy but also in our private lives.

It is interesting to be able to follow the development of lighting technique from one exhibition to another. Millions have been able to enjoy the latest novelties in illumination in Paris, but because of this very fact the organizers of the next

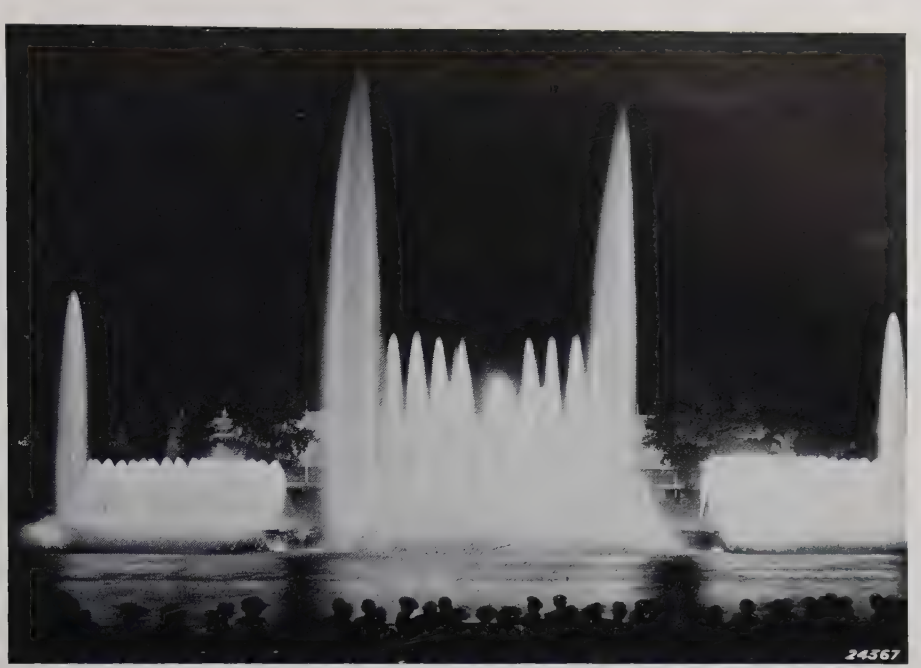


Fig. 9. Fontaines de Jeumont. One of the innumerable aspects which these fountains display to the public.

exhibitions find themselves faced with the task of going still farther. It is with some suspense that we await the results of the world exhibitions which are even now being planned. In the first place there is the exhibition in New York in 1939 and then that in Rome in 1942.

Doubts are sometimes felt about the benefits to be derived from world exhibitions, but for lighting technique they certainly form milestones along the road of progress, and each one is a stimulant toward further achievement. In this respect they are undoubtedly of the greatest importance.

RADIO LANDING BEACONS FOR AERODROMES

by P. ZIJLSTRA.

Summary. Following a short introduction dealing with the principles of radio landing beacons and a consideration of the advantages and disadvantages of long and short waves for this purpose, the radiation diagrams of modern landing beacons working on ultra short waves are discussed in detail. Finally a description is given of the Philips ultra short wave beacon transmitter B.R.A. 075/4.

Introduction

In an article on position finding and course plotting on board an aeroplane, in the June number of this periodical [1]), the functioning of the Philips long wave landing beacon B.R.A. 101 was explained. Different signals, are heard on either side of the course line which crosses the aerodrome. for example dots on the one side and dashes on the other. These signals complement each other in such a way that when both signals are equally strong an uninterrupted constant signal is observed. This is made possible by transmitting from a vertical aerial and a loop aerial, the ratio of whose currents can be regulated. By a combination of the circular radiation diagram of the vertical aerial with the figure of eight diagram of the loop aerial a heart shaped radiation diagram is obtained when the maximum field strengths are the same, as shown in *fig. 1.* The phase of the loop current is reversed

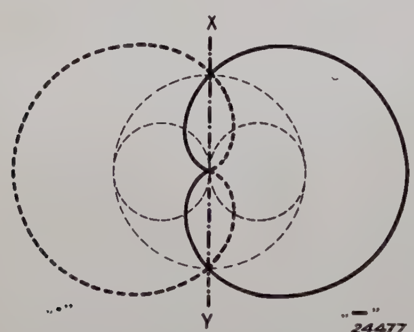


Fig. 1. Heart-shaped radiation diagram of a long wave beacon consisting of the circular diagram of a vertical aerial and the figure-of-eight diagram of a loop aerial. XY in this and the following figures is always the course line. To the right of the course line dashes are audible, to the left dots.

in a dot-dash rhythm, so that the heart-shaped diagram is mirrored along the course line XY, and therefore the full line and the broken line diagram are sent out alternately in the dot-dash rhythm and together form the total radiation.

The nature of the signal heard when flying „off course" (either dots or dashes) determines the direction which must be steered to reach the course line. By means of the continuous signal on the course line it is possible to fly directly toward the aerodrome, and to estimate roughly the distance to the landing beacon from the field strength read from the corresponding meter. In addition two warning beacons are set up several kilometres apart along the course line, and close to the boundary of the aerodrome. These are weak transmitters which radiate a signal of their own audible only from directly above. The first indicates to the pilot that he may begin to descend and the second that he may land. Such a landing installation on long waves has already proved its usefulness many times.

It is desirable that one should hear an obvious difference in the intensity of the dots and dashes upon a slight deviation from the course line (cf. fig. 10). The smaller the angle at which the full line diagram and the broken line diagram cut each other on the course line, the sharper the landing beacon indicates the course line, since a correspondingly smaller deviation is observable.

By making the signal received from the vertical aerial weaker than that from the loop, the course line of the long wave beacon can be made sharper than is shown in fig. 1.

Choice of wave length.

One advantage of the use of long waves for landing beacons is that the beacon signal may be heard with the ordinary communication receiver of the aeroplane, and no special apparatus for blind landing by means of radio signals need be installed on board. One important disadvantage, however, is that in the long wave range only a very limited frequency band is available for beacon transmitters. With a multiplicity of beacon transmitters there is therefore the danger that they may interfere with each other. Atmospheric disturbances may also prove troublesome in the reception of long waves.

Landing beacons of the types B.R.A. 075/4 and B.R.A. 200/8 work on a wave length of 9 m which is internationally reserved for landing beacons, and

[1]) Philips techn. Rev. *2*, 184, (1937).

the corresponding warning beacons on 7.9 m. The combination of vertical and loop aerial usual for long wave landing beacons cannot be adopted without modification for short waves. The dimensions of the loop would be of the same order of magnitude as the wave length, and consequently the currents in the loop would no longer have the amplitudes and phases necessary for the formation of the figure-of-eight diagram. We must therefore choose a different aerial system for the beacon transmitter on short waves. It will be shown that this may be done in such a way that, in addition, the course line is more sharply demarcated than in the case of the long wave beacon whose radiation diagram was given in fig. 1.

For the sake of simplicity in the receiving apparatus on board the aeroplane, the beacon transmitter for ultra short waves is modulated with an audible frequency of 1150 cycles per second.

The symmetry of the radiation diagram

With short waves various different aerial systems may be employed for the beacon transmitter. For example the aerial may consist of two directional antennae at an acute angle to one another and which are energized in turn in a dot-dash rhythm so that together they form the radiation diagram which is given in an idealized form in *fig. 2*. Another

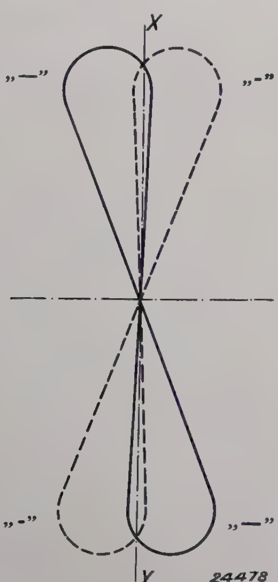


Fig. 2. Radiation of two directional aerials which make an acute angle with each other. In the first and third quadrants dots are heard, in the second and fourth dashes.

suitable aerial system consists of a vertical aerial *A* of a half wave length, flanked on either side by reflectors *R*. These reflectors are alternately rendered ineffective in a dot-dash rhythm by means of a relay so that the radiation diagram given in *fig. 3* is produced.

From these two simple examples we may now easily distinguish between the two possible methods of indicating the course line. The regions where dots of or dashes respectively may be heard alternate quadrant by quadrant in fig. 2, but in fig. 3 they

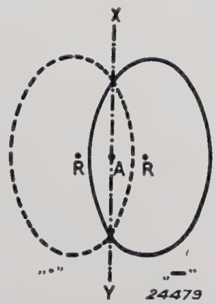


Fig. 3. Radiation diagram of a vertical aerial *A* with two reflectors *R*. To the right of the course line *XY* dashes are heard, to the left dots.

alternate only on either side of the course line, as was the case with the long wave beacon of fig. 1.

In the case of a beacon with quadrant zones as in fig. 2, one always hears dashes to the right of the beacon line and dots to the left, independently of the direction in which one approaches the aerodrome along this line. When dashes are heard, therefore, one must always turn to the left, and when dots are heard, to the right. In flying over the aerodrome another quadrant is entered and the nature of the signal changes. If the aerodrome has already been passed, dots are heard to the right and dashes to the left, as may be seen from fig. 2.

With a beacon having only two zones the same signal is always heard on one side of the beacon line, and this signal is not reversed when the aerodrome has been passed. In such a case the course must be followed by compass in order to know in which direction to turn to reach the beacon line when either dots or dashes are heard. Further, in the case of the two-zone beacon, there is the advantage that there can be no false course line perpendicular to the correct one, as may be the case with a beacon having quadrant zones when the field strength at the transition line from dots to dashes is not zero because of field distortions by large metal objects, such as for example hangars.

For economical operation of the landing beacon the radiated energy must be confined as much as possible to the landing line. In this repect the beacon with quadrant zones (*fig. 2*), which theoretically has no radiation perpendicular to the course line, is more satisfactory than the beacon with two zones (fig. 3) which sends out considerable radiation in that direction.

Aerial systems employed

As we have seen, a loop aerial cannot be used for the short wave beacon; in place of this two „half wave" vertical aerials were placed at a distance of one wave length from each other. Since the circuit is so arranged that the currents and the voltages in the two vertical aerials are always in opposite phases, we shall continue to call this combination the loop system (A and B in *fig. 4*). Let us now consider the field

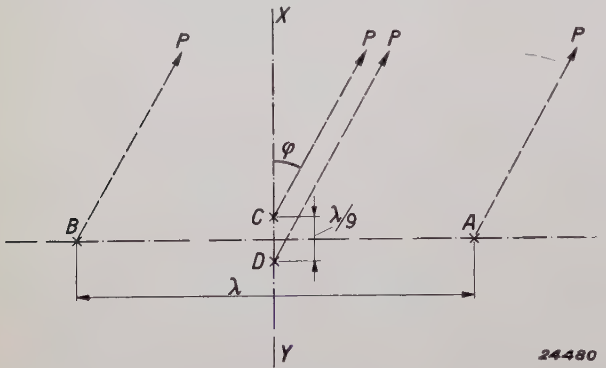


Fig. 4. Aerial system for an ultra short wave beacon. The two vertical aerials A and B are placed at a distance of one wave length λ from each other. A U-aerial, whose two arms C and D are separated by a distance of $\lambda/9$, is placed midway between A and B and with its plane perpendicular to AB. P is any given point in the horizontal plane which is so far away from the aerial that the various lines joining it to P may be considered parallel.

produced by A and B at point P at a great distance R from the middle of the line joining A and B ($R \gg \lambda$) and lying in the horizontal plane which makes an angle φ with the beacon line. At an angular frequency ω the two vertical aerials of opposite phase and the same amplitude F_m produce the following fields:

$$F_A = F_m \sin \omega \left(t - \frac{R - \frac{\lambda}{2} \sin \varphi}{c} \right) \text{ and}$$

$$F_B = F_m \sin \left\{ \omega \left(t - \frac{R + \frac{\lambda}{2} \sin \varphi}{c} \right) + \pi \right\}, \quad (1)$$

since $\lambda/2 \sin \varphi$ is the difference in path for the waves from A or B reaching point P.

The mean value of the resulting field at point P is then:

$$F_P =$$

$$2 F_m \sin \left\{ \omega \left(t - \frac{R}{c} \right) + \frac{\pi}{2} \right\} \cos \left\{ \omega \left(\frac{\lambda/2}{c} \sin \varphi \right) - \frac{\pi}{2} \right\}$$

$$= 2 F_m \sin (\pi \sin \varphi) \cos \omega \left(t - \frac{R}{c} \right) \quad (2)$$

This field is therefore zero at the beacon line and perpendicular to it, while it is at a maximum at angles of 30° with the beacon line, and shifted in phase 90° with respect to the fields which each arm produces separately. For the mean value of the field strength we thus obtain the radiation diagram given in *fig. 5* consisting of four loops.

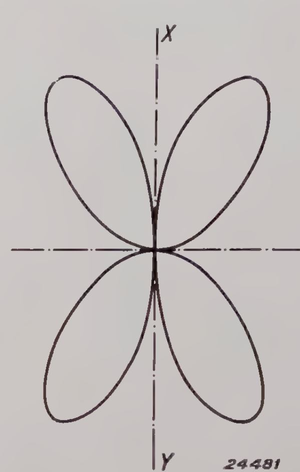


Fig. 5. Four-loop radiation diagram of the two vertical aerials A and B of fig. 4.

This four-loop diagram is still completely symmetrical with respect to the landing line, and we must add still another radiation in order to indicate the beacon line. A radiation diagram with quadrant zones may be obtained by introducing a U-aerial with its plane along the beacon line (C and D in fig. 4) between the aerials of the loop system. The U-aerial may be obtained by bending a tube of a half wave length $\lambda/2$, in a U-shape with a base of $\lambda/9$, so that the arms are somewhat less than $\lambda/4$ in length. The U-aerial is fed through its base, which is placed at the height of the middle of vertical aerials A and B, in such a way that the two arms C and D are in opposite phase, and each one is in phase with one of the aerials A and B. At point P the two arms of the U-aerial then produce the following fields:

$$F_C = F_u \sin \left\{ \omega \left(t - \frac{R - \frac{\lambda}{2} \frac{\cos \varphi}{9}}{c} \right) \right\} \text{ and}$$

$$F_D = F_u \sin \left\{ \omega \left(t - \frac{R + \frac{\lambda}{2} \frac{\cos \varphi}{9}}{c} \right) + \pi \right\} \quad (3)$$

The field produced by the U-aerial at P is thus:

$$F_P = 2 F_u \sin \left(\frac{\pi}{9} \cos \varphi \right) \cos \omega \left(t - \frac{R}{c} \right). \quad (4)$$

This field is zero perpendicular to the beacon line and maximum on the beacon line, so that we

obtain the radiation diagram for the U-aerial given in *fig. 6* and consisting of only two loops.

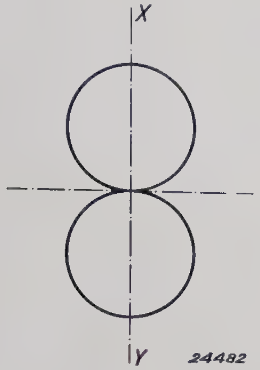


Fig. 6. Two-loop radiation diagram of the U-aerial (*CD* of fig. 4).

The total field produced at *P* by the whole aerial system is the sum of the two expressions (*2*) and (*4*):

$$F_P = 2\left\{F_u \sin\left(\frac{\pi}{9}\cos\varphi\right) + F_u \sin(\pi\sin\varphi)\right\}\cos\omega\left(t-\frac{R}{c}\right) \quad (5)$$

Since the phases of the fields produced by the loop and U-aerials (eq. (2) and (4)) are the same, we can obtain the total radiation diagram of *fig. 7*

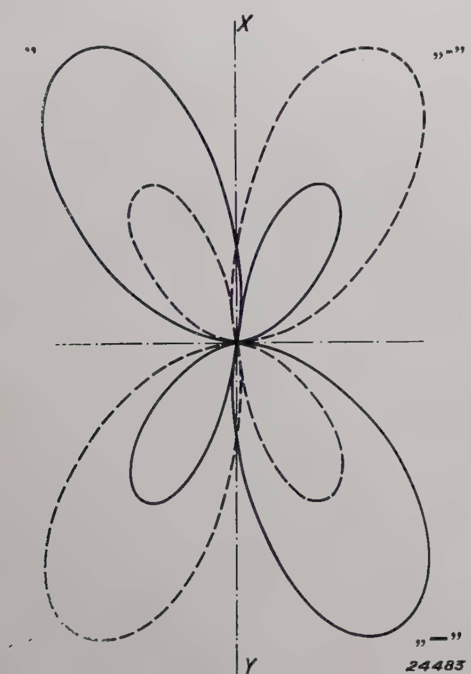


Fig. 7. Resultant radiation diagram for the aerial system shown in fig. 4.

by adding the two polar diagrams of figs. 5 and 6 with the correct sign. If the phase of the loop system is reversed, the total field at *P* is given by:

$$F_P = 2\left\{F_u \sin\left(\frac{\pi}{9}\cos\varphi\right) - F_m \sin(\pi\sin\varphi)\right\}\cos\omega\left(t-\frac{R}{c}\right) \quad (6)$$

In this way the full line and the broken line radiation diagrams of *fig. 7* are produced. If the loop current is reversed in a dot-dash rhythm the zones in which dashes are louder than dots and vice versa alternate in the successive quadrants.

If a beacon transmitter with half zones is desired, we may add an ordinary vertical aerial of a half wave length to the loop system having the radiation diagram given in fig. 5. This aerial is placed midway between the two wires *A* and *B* of the loop system, while the current is shifted 90° in phase with respect

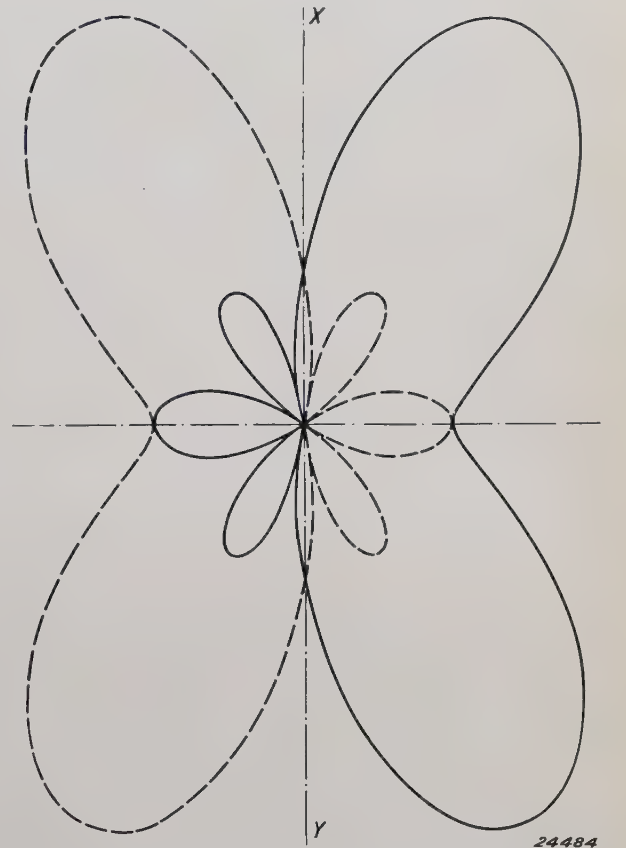


Fig. 8. Total radiation diagram for an aerial system consisting of two vertical aerials one wave length apart and working in opposite phase, with another vertical aerial half way between them whose current differs in phase by 90° from that in the first two.

to that of the loop system. The vertical aerial then radiates a field which is in phase with the field of the loop system, so that the polar diagram of the resultant average field is simply the sum of the circular radiation diagram of the vertical aerial and the four-loop diagram given in fig. 5 of the loop system, taken with the correct sign. The field at point *P* is:

$$F_P = \left\{F_a \pm 2\,F_m \sin(\pi\sin\varphi)\right\}\cos\omega\left(t-\frac{R}{c}\right), \quad (7)$$

when F_a represents the average value of the field of the added vertical aerial. In *fig. 8* is given the

total radiation diagram for the case when F_m is taken equal to F_a; the full and the broken line figure refer again to the two directions of the loop current.

In the above-described manner we have obtained a beacon transmitter with half zones in which dots and dashes are heard respectively, while the energy radiated is fairly well confined to the direction of the landing line along which it is desirable to be able to hear the beacon signals clearly. One disadvantage however is that perpendicular to the beacon line dots and dashes are also heard equally clearly, so that a false landing course might be given in that direction. This can be prevented by a slight modification; we have to arrange the loop system whose phase is reversed in a dot-dash rhythm so that it fails to radiate exclusively on the beacon line. This may be done by placing the two vertical aerials at a distance of not exactly one wave length from each other. If we take a separation of $^5/_6\ \lambda$, for example, the resultant field of the beacon transmitter becomes:

$$F_P = \left\{ F_a \pm 2\, F_m \sin\left(\frac{5}{6}\pi \sin\varphi\right)\right\} \cos\omega\left(t - \frac{R}{c}\right), \quad (8)$$

the radiation diagram of which is given in *fig. 9*

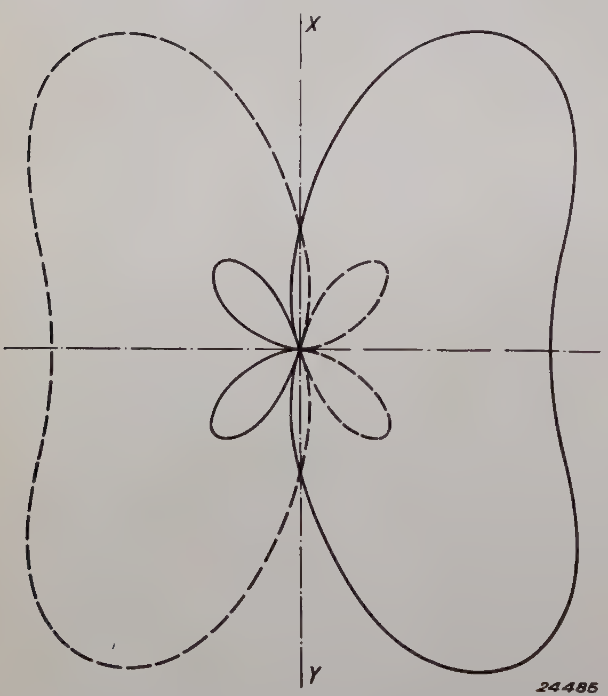


Fig. 9. Radiation diagram for the same system as in fig. 8, but in this case with the two vertical dipoles which form the loop aerial situated only $^5/_6\ \lambda$ apart.

for $F_m = F_a$. The avoidance of a false course has been made possible somewhat at the expense of the confinement of the radiation to the direction of the beacon line.

Sharpness and regulation of the course line

With a small deviation $\mathrm{d}\varphi$ from the course the difference in the field strengths for dots and dashes is $\mathrm{d}F$ as shown in *fig. 10.* For a sharp course the

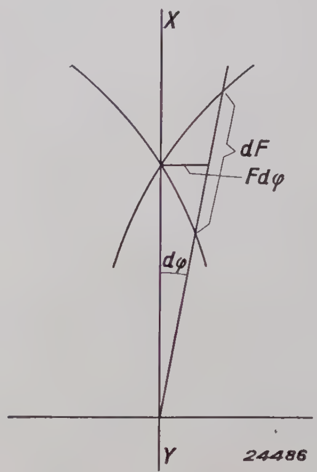


Fig. 10. Difference in intensity $\mathrm{d}F$ between dots and dashes with a slight deviation $\mathrm{d}\varphi$ from the course line.

difference $\mathrm{d}F$ in the field F must be audible at a small deviation $\mathrm{d}\varphi$. A good standard for the sharpness of the course line is therefore:

$$S = \lim_{\varphi \to 0} \frac{\mathrm{d}F}{F\,\mathrm{d}\varphi} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (9)$$

For the combination of two rods with a U-aerial the sharpness of the course line thus becomes:

$$S = \frac{F_m\,\pi}{F_u \sin\frac{\pi}{9}} = 9.2\,\frac{F_m}{F_u} \quad . \; . \; . \quad (10)$$

For the last aerial system discussed in which the rods were placed $^5/_6\ \lambda$ apart, we obtain:

$$S = \frac{2\,F_m \cdot \frac{5}{6}\pi}{F_a} = 5.2\,\frac{F_m}{F_a} \quad . \; . \quad (11)$$

If we now keep in mind that the field F_m from one of the arms of the loop aerial is always several times as large as that of one of the arms of the U-aerial or of the vertical aerial F_a, we see that these aerial systems are always much sharper than for example the aerial system shown in fig. 3, whose sharpness S is only of the order of magnitude one.

For satisfactory observation by the pilot of the aeroplane it is desirable that the difference in intensity between dots and dashes be at least four decibels. This means that the ratio of the squares of the amplitudes F_1 and F_2 of dots and dashes respectively must be at least $10^{0.4}$:

$$\left(\frac{F_1}{F_2}\right)^2 = 10^{0.4} \text{ or } \frac{F_1}{F_2} = 1.7 \quad . \; . \; . \; . \quad (12)$$

In the combination of two rods with a U-aerial for which F_u is taken equal to F_a, the above relation is already reached at an angle of 1° 30′ with the course line; if F_m is made greater than F_u it is true for still smaller angles. This shows how sharply the course line is indicated by these beacons. Such a sharp beacon is also less sensitive to disturbances, because, due to the great difference in field strength between dots and dashes, the influence of a given interfering field is of course relatively less.

The beacons here described are not only inherently very sharp, they have in addition the advantage of allowing regulation. As may be seen from formulae (10) and (11), the sharpness of the course line may be regulated by changing the ratio between the fields from the different components of the aerial system. It is also possible to change the direction of the course line. This is done by allowing the two arms of the loop aerial to radiate in not quite exactly opposite phases. If the difference in phase is $\pi - \lambda$, then, with the combination of two rods and a U-aerial, the deviation from the course line becomes:

$$\varphi = \text{arc sin} \frac{\gamma}{2\omega} \cdot$$

Thus for example if $\lambda = 15°$, $\varphi = 2° 23'$. Small deviations from the course line due to field distortion by metal hangars and the like may in this simple way be compensated.

Because of the symmetrical arrangement no total EMF is induced in the U-aerial by the current change in one arm of the loop aerial; there is said to be no radiation coupling. Upon changing the phase of the loop current we are therefore not concerned with a compensation for the changes thereby caused in the currents of the U-aerial, and this holds good for the aerial systems which produce the radiation diagrams of figs. 8 and 9.

Arrangement of the Philips ultra short wave beacon transmitter type B.R.A. 075/4.

Since the beacon transmitter must interfere as little as possible with other transmitters, its working radius must not be greater than 30 km. Because of the great sharpness of the ultra short wave beacon a high absolute field strength is not necessary. The final stage for the loop aerial may, for instance, consist of two T.B. 1/60 valves with a power of 60 watts, connected in push-pull. The final stage for the U-aerial may have even less power. The coupling of this final stage with the oscillator is variable, because with strong coupling the oscillator might easily be affected. For that reason the final stage for the U-aerial has been made similar to that for the loop aerial, and the coupling may then be looser.

The circuit of the beacon transmitter is shown in the block diagram of *fig. 11*. The frequency of the self-generating oscillator *1* is kept constant by placing the whole oscillator circuit in a thermostat and stabilizing the anode voltage. The heating voltage is supplied by a separate rectifier. The anode self-inductance is divided into two parallel portions which are coupled respectively with the final stage *2* for the U-aerial, and the phase-reversing stage *3*. The latter consists of two valves whose grids are in phase, and whose anode alternating voltages are in opposite phase. In a dot-dash rhythm the grids of these two valves are in turn made so negative that the valve concerned passes no anode current. The anodes of these two valves thus in turn supply the excitation voltage for the final stage of the loop aerial, whose phase is therefore reversed in a dot-dash-rhythm. The two valves are rendered inactive in turn in such a way that no intermediate state exists at which neither has a closed grid circuit. The occurrence of "click" phenomena in the receiver telephone is prevented in this way.

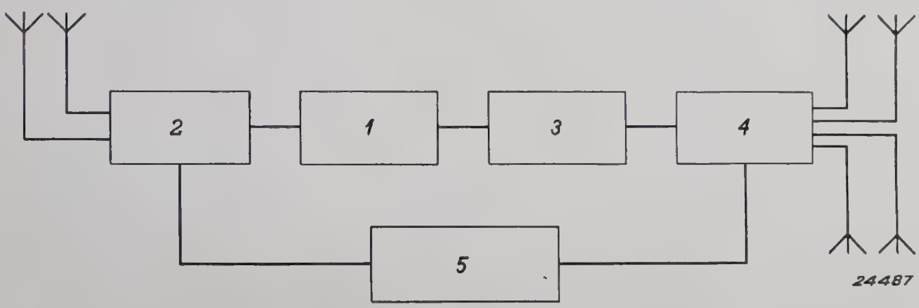


Fig. 11. Block diagrams of the ultra short wave beacon transmitter type B.R.A. 075/4. *1* oscillator stage; *2* final stage for U-aerial; *3* phase-reversing stage; *4* final stage for the loop aerial and *5* modulator.

The final stage *4* for the loop aerial also has an anode self-inductance divided into two parallel portions, each of which is coupled with the feeder of one of the two vertical rod aerials. The strength and the phase of these couplings can be altered for the purpose of regulating the sharpness and direction of the course.

The modulator *5* is a self-generating valve which feeds two parallel modulator stages each of which is coupled to one of the two final stages by means of a transformer. The various heating currents are alternating currents, except for that of the oscillator, and they are kept constant by regulator valves. The various negative grid voltages and the anode voltage for the modulator are supplied by separate rectifiers. The complete beacon transmitter is housed in a cabinet illustrated in *fig. 12.*

At present a new type of landing beacon type B.R.A. 200/8 is being built, and it will be installed at Schiphol. In addition to changes in the transmitter, the aerial system also differs somewhat from that described in this article. The radiation diagram corresponds in principle with that given in fig. 9.

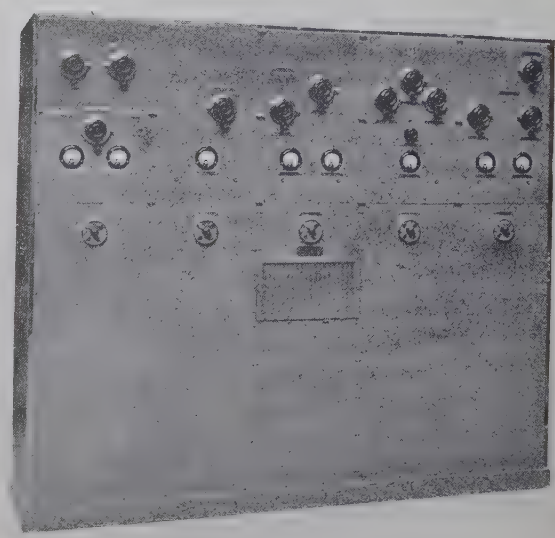


Fig. 12. Philips ultra short wave beacon transmitter type B.R.A. 075/4.

THE EXAMINATION OF THE MACRO-STRUCTURE OF MATERIALS AND PRODUCTS WITH THE HELP OF X-RAYS. III

by J. E. DE GRAAF.

The diagnosis of technical faults in casting.

We shall discuss several faults which may occur in castings without making any claims as to completeness either with respect to the faults or to their causes. It is also possible to examine the casting moulds with X-rays in order to establish the correct position of cores etc. [1]); this however will not be discussed in this article.

The faults in a casting may be divided into the following main categories: gas pockets, shrinkage faults and slag enclosures. In the case of the first two considerable difference in shape is possible according as the cavities occur in liquid metal, or in metal in a semi-solid state where solid crystals are already present in a still fluid mass.

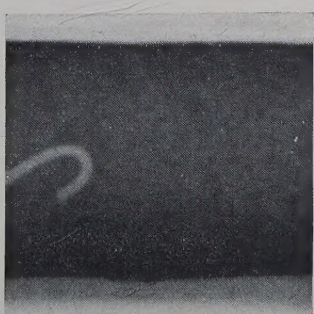
Group I. Gas Pockets

24347

Fig. 1. Gas pockets occurring in liquid metal:

Characteristics: round spots, fairly large in size (up to several mm), with smooth, sharp outlines and heavy blackening compared with that due to flat faults; occurring sometimes alone and sometimes in groups.

Causes: gas bubbles arising out of the mould or from the melt itself into the liquid metal.



24348

Fig. 2. Gas pockets occurring in semi-solid metal.

Characteristics: small irregular spots with slight blackening and very vague outlines; they are distributed at random throughout the whole casting; with very fine cavities a cloudy image often appears.

Causes: development of gas in the melt itself during solidification.

Group II. Shrinkage Faults

24349

Fig. 3. Shrinkage cavity which occurred in the presence of liquid metal.

Characteristics: large spots of quite random shape, often with rather sharp contours at the top and a more or less vague edge or offshoots below, heavy blackening.

Cause: a large, slowly solidifying volume of metal is cut off too early from the supply of material (for example because of the closing of a too restricted pourer channel due to freezing).

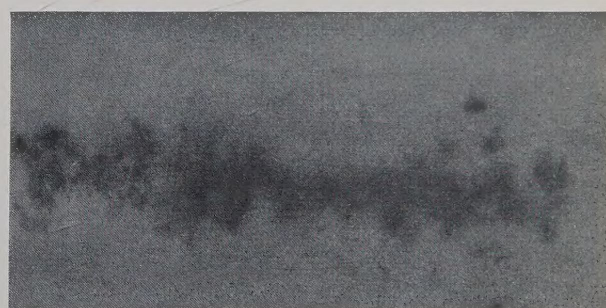


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Fig. 4. Shrinkage cavities which occur in semi-solid metal.

Characteristics: small irregular spots, with slight blackening and very vague outlines; situated at random in particular portions of the casting; difference from fig. 2: the gas cavities may occur throughout the whole casting, the shrinkage faults cannot occur in portions where shrinkage was

1) H. Reiniger: Die Giesserei **17**, 40 (1930).

compensated by a steady supply of metal. Causes: the cutting off of the supply of material at a relatively late stage, so that shrinkage cavities appear only after many crystals have already been formed.

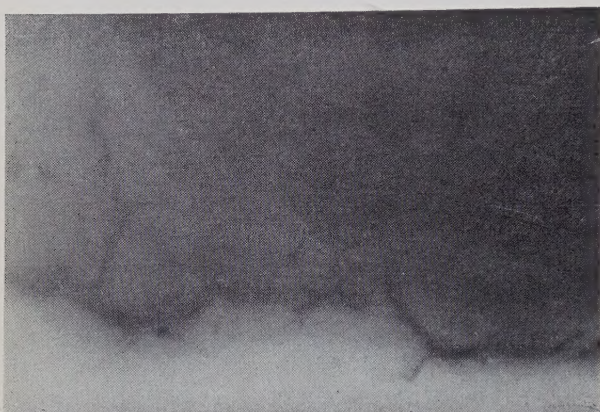

Fig. 5. Shrinkage cracks which occur in semi-solid metal.

Characteristics: the contrast depends very much upon the direction of the X-rays (cf. Philips techn. Rev. **2**, 351 (1937)); relatively broad lines under favourable conditions, very black and with many branches.

Causes: due to a temporary state of stress a crack occurred rather than a cavity; the branches are due to the still only slight adhesion between the crystals already present in the mass; if the outer crust is already sufficiently strong the fault is often invisible from the outside.

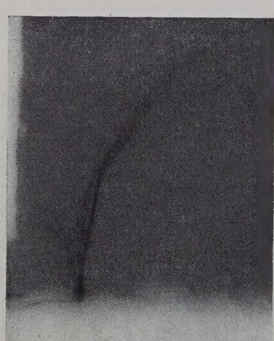

Fig. 6. Shrinkage cracks, which occur in solid metal.

Characteristics: the contrast is closely dependent on the direction of the X-rays, fine lines, sharper than in the previous case, very black and with few branches; the fault is visible on the surface.

Causes: excessive stresses in the solid state which have their highest values at the surface of the object.

Group III. Sand and slag enclosures

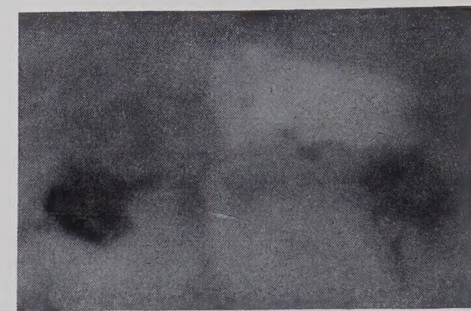

Fig. 7. Sand enclosures.

Characteristics: usually vague spots, irregular in shape and blackness, often with short branches and sometimes fine cracks; the fault is almost always directly below the surface, in contrast to shrinkage cavities.

Cause: a bit of sand has fallen out of the mould upon the rising iron (see the white spot in fig. 7: the casting is thicker at that point).

Group IV. Various Faults

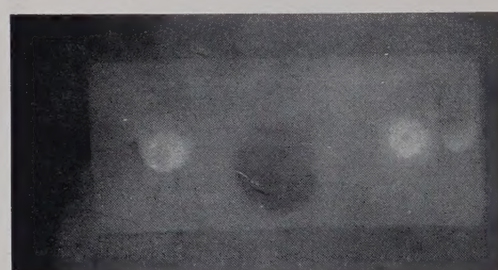

Fig. 8. Casting badly fused with the core support, (rectangular plate with two feet), immediately recognizable from the photograph. If black bands may be seen around parts cast in, these parts are practically loose (chance of leakage or fracture).

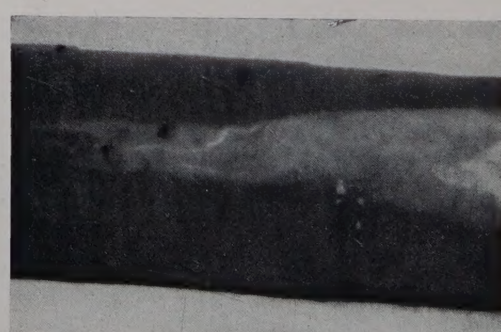

Fig. 9. Segregation (local increase of concentration) of a heavy metal from its alloy.

Characteristics: light spots which do not correspond with surface projections and must therefore be caused by heavier metal (cavities are darker).

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS GLOEILAMPENFABRIEKEN

No. 1216: K. F. Niessen: Eine Verschärfung des verbesserten Sommerfeldschen Fortpflanzungsformel für drahtlose Wellen zur Ausbreitung ihres Gültigkeitsgebietes nach kleineren Abständen (Ann. Physik **29**, 569 - 584, Aug. 1937).

Formulae are derived for the field at the earth's surface of a vertical, infinitesimally small dipole transmitter situated directly above the earth considered as flat, and particularly for the field at a distance of several wave lengths. The theory given by Sommerfeld in 1926 for the field at greater distances is made more rigorous with the help of an exact expression for the π function of Hertz derived by van der Pol and Niessen, in which account must be taken of terms which appear especially in this case because of the slightness of the distance. Different formulae are derived according as the electric or the magnetic field must serve for reception. These formulae coincide in the Sommerfeld region. The constants which describe the properties of the ground are chosen arbitrarily in this article. For several practical values the change of the intensities is shown as a function of the distance measured in wavelengths, in order to shown the deviation from the extrapolation to smaller distances from the formula given by Sommerfeld in 1926 which agrees with that of Weyl.

No. 1217: K. F. Niessen: Zur Entscheidung zwischen den beiden Sommerfeldschen Formeln für die Fortpflanzung von drahtlosen Wellen (Ann. Physik **29**, 585 - 596, Aug. 1937).

This article was written in response to the fact that up to recently use was made in the literature of the formula derived by Sommerfeld in 1909 for the field of a dipole transmitter, in spite of the fact that Sommerfeld himself in 1926 had given another in its place (in Riemann-Weber, for example) which agreed with a formula deduced in quite a different way by Weyl in 1919. The exact expression derived by van der Pol and Niessen in 1930 also leads to the same result as a first approximation. The purpose of the article was to discover where the error lay in Sommerfeld's first treatise.

No. 1218: E. M. H. Lips: An analysis of the structure of pearlitic cast iron (Gieterij **11**, 235 - 239, July-Aug. 1937).

In this lecture, given before the Netherlands Society of Foundry Technicians, the fact was discussed that normal pearlitic cast iron consists of a foundation mass of alloyed pearlitic steel which has a high tensile strength and slight wear, in which a larger number of graphite flakes are imbedded, with the result that the tensile strength is reduced to about one third of that of the foundation mass. The tensile strength of pearlitic cast iron can be raised by making the graphite inclosures smaller in number and more round in shape. In order to retain the low modulus of elasticity, the high damping capacity and the ease of working of cast iron, minimum content of carbon should be about 2.5 per cent, to which corresponds a maximum tensile strength of 35 to 40 kg/mm^2.

No. 1219*: R. Houwink: Elasticity, Plasticity and Structure of Matter (with a chapter on the plasticity of crystals by W. G. Burgers); 394 pages. 1937 (Cambridge Univ. Press).

In this book a survey is given of the modern views of elasticity and plasticity phenomena and of their relation to the structure of matter. Insight obtained from physical and chemical viewpoints as well as results attained from the technological side in the development of new materials are discussed. Various specialists have collaborated in the chapters on particular substances.

No. 1220*: J. H. de Boer: Elektronenemission und Adsorptionserscheinungen; 334 pages, 1937 (Joh. Ambr. Barth, Leipzig).

This book is the German edition of "Electron Emission and Adsorption Phenomena" by the same author, published by the Cambridge University Press in 1935. The author has made use of the opportunity to include the further developments in this subject. Further elucidations have also been introduced à propos of desires expressed in the discussions of the English edition. New conceptions

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*) An adequate number of reprints for the purpose of distribution is not available of those publications marked with an asterisk. Reprints of other publications may be obtained on application to the Natuurkundig Laboratorium, N.V. Philips' Gloeilampenfabrieken, Eindhoven (Holland), Kastanjelaan.

are given especially in regard to the ionization state of adsorbed atoms and the theory of the disturbed lattice positions in semi-conductors.

No. 1221: M. J. Druyvesteyn: Der Anodenfall in den Edelgasen He, Ne und Ar. (Physica 4, 669 - 682, Aug. 1937).

The degree to which the voltage on the tube depends upon the distance between the electrodes is determined for helium, neon and argon in a glow discharge as well as in an arc with a hot cathode. At a definite separation D the potential rises sharply since an anode drop occurs. The distance D is practically the same for a glow discharge and for an arc. The product of D and the gas pressure is found to be independent of the pressure at high gas pressures. For low pressures however it decreases with the pressure, since D can not be much greater than the diameter of the tube. By considering the Faraday dark space as a plasma, this behaviour can be explained. Measurements of the tube voltage as a function of the gas pressure at a constant distance between the electrodes are found to furnish results which agree with this.

No. 1222: J. A. M. van Liempt and J. A. de Vriend: Testing synchronizers (Physica 4, 703 - 714, Aug. 1937).

A description is given of the synchronizers used in photography with flash-light lamps, and their practical significance is explained. With the aid of a cathode ray tube the time constant and the fluctuation of a synchronizer is determined. It is explained that the flash time of flash-light lamps used with synchronizers must not be too short. The article ends with the description of a method for the correct adjustment of synchronizers, which has in the meantime also been given in Philips Technical Review **2**, 334, 1937).

No. 1223: C. J. Bakker: On the number of neutrons emitted by a radium-beryllium source (Physica 4, 723 - 729, Aug. 1937).

The number of neutrons emitted by a radium-beryllium source per sec and per milli-curie of radium is measured according to a method given by Amaldi and Fermi, and is found to be $(2.1 \pm 0.2) \times 10^4$.

CONTENTS OF PHILIPS TRANSMITTING NEWS.

The editor proposes to announce regularly in future in the Philips Technical Review under "Abstracts of Recent Scientific Publications" the contents of "Philips Transmitting News" as soon as published. This journal, which is devoted to transmitter engineering, appears 4—6 times a year in German and English. For subscriptions kindly apply to Dept. Zendwezen of the N. V. Philips' Gloeilampenfabrieken, Eindhoven.

Of the fourth year's edition already appeared

in March 1937 Vo. IV, No. 1:

K. Posthumus and Tj. Douma: Some considerations of the frequency stability of ultra-short wave driving oscillators (continuation).
Short-wave broadcast transmitters type K.V.F.H. 10/12 for British India.
J. van der Mark: Television.

In May 1937. Vol. IV. No. 2:

F. M. Duinker: Filters for rectifiers.
A practical apparatus for radio-technical calculation.
The watercooled pentode type PA 12/15.
H. G. Boumeester and M. J. Druyvesteyn: Gas-filled triodes.

in July 1937. Vol. IV. No. 3:

K. Posthumus: The watercooled pentode type PA 12/15 an ultra short wavelength.
Aerodrome transmitters for Turkey.
H. G. Boumeester: Manufacture of modern transmitting valves.

in Sept. 1937. Vol. IV. No. 4:

J. P. Heyboer: The use of pentodes in radio-transmitters.
New Aircraft equipment for the Royal Dutch Airlines.
W. Albricht: A transmitter for television experiments.
Review of scientific publications.
